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Thailand's energy security indicators

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ABSTRACT

This study presents an assessment of the energy security of Thailand using nineteen indicators. The assessment period is for a 45 year period (1986–2030), and used published data for 1986–2009, and applying three energy scenarios for the period 2010–2030. The three scenarios considered were "high economic growth and least cost option (HEG&LC)", "low carbon society (LCS)", and "current policy (CP)". The results show that LCS scenario shows higher energy security or lower vulnerability to energy risk on a long term. However, to achieve this, the additional target of energy saving by 2030 should be changed from 25% reduction of energy intensity of final energy consumption to 60% energy intensity reduction of primary energy compared to 2009 level. One benefit would be an increase in the non-carbon incentive fuel portfolio by 33% of total primary energy supply in 2030. A reduction in crude oil and natural gas domestic production will be offset by an increase in their imports. CO_2 emission reduction of 123 $MtCO_2$ and improvements in domestic energy reserves will also result.

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1. Introduction

Energy is an important input for providing the basic services of human needs, and is a key input to sustainable development and poverty reduction efforts. Thus, the role of energy is strongly linked to social, economic, and environmental development [1].

The world's energy consumption increased from 11,536 Mtoe (1.75 toe per capita) in 2008 to 12,002 Mtoe in 2010 (4% increase) [2,3], while in the Asia-Pacific, the corresponding values were 4092 Mtoe and 4574 Mtoe, respectively. The share of Asia-Pacific's energy consumption to that of the world increased from 36% to 38% during the same time period [3] (and in terms of per capita consumption, from 0.94 to 1.00 toe per capita [4,5]). IEA reports [6] that the world primary energy demand would be 14,896 Mtoe (1.95 toe per capita) in 2020 and 18,048 Mtoe (2.13 toe per capita) in 2035. The primary energy demand in the non-OECD Asia would be 5285 Mtoe (1.33 toe per capita) in 2020 and 7240 Mtoe (1.66 toe per capita) in 2035. The share of fossil energy resources in the overall energy supply in 2008, 2020 and 2035 based on current policies is 9964 Mtoe (81%), 11,916 Mtoe (80%) and 14,346 Mtoe (79%), respectively [6]. This illustrates the significant growth of energy demand in the world and Asia, and the role of fossil resources in the coming decades. One important implication of fossil energy use is the emission of green house gases, mainly carbon dioxide. This is estimated at 29.4 $GtCO_2$ in 2008, and is expected to reach 40 $GtCO_2$ in 2030 [6].

Energy access, especially modern energy (electricity, LPG) to the poor is an important concern to the developing world. UNDP reports [7] that 1.4 billion people have no access to electricity and about 3 billion people rely on solid fuels (traditional biomass and coal) to meet their basic needs. To meet the target of achieving universal access to modern energy services by the poor within 2030, the additional investment required is estimated at $756 billion (less than 3% of the projected global energy investment) [7].

The world's fossil energy reserves and their rate of depletion are given in term of reserves-to-production ratio (RPR) (in unit of years). At the end of 2010, the world's RPR of oil, natural gas and coal were 46, 58, 118 years, respectively, and for the Asia-Pacific region, it was 15, 33, and 57 years, respectively [3].

This limitation (and depletion) of fossil energy reserves coupled with the increasing demand for energy, accessibility and affordability of alternative energy resources, and the environment acceptability of energy generation and consumption are issues considered under energy security, and is therefore an important concern for all countries. Energy security defined by countries and international organizations (see Table A.1 in the appendix) depends on national priorities and their national concerns [8–19].

The Asia Pacific Energy Research Centre defines "Energy security" as "the ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy" [8]. Interestingly, World Energy Council defines it in two different perspectives—energy-consuming countries and energy supplier [13].

In general, the energy security of developing countries refers to "enough energy supply (quantity and quality) to meet all requirements at all time of all citizens in affordable and stable price, and it also leads to sustain economic performance and poverty alleviation, better quality of life without harming the environment" [10,14–18], whereas, developed country energy security definition refers to "a resilient energy system and securing the amount of energy required for people's life, economic and social activities, defense and other purposes at acceptable prices" [9,12].

An analysis of the definition of energy security resulted in 13 criteria, which are listed in Table 1. This shows the map of the various criteria and their corresponding sources. For example, the criterion "covering energy requirement/demand diversity" is noted in the energy security definition of WEC, APERC, IEA, Brazil, India, Japan, Senegal, and Thailand, but it is not explicitly considered by Kenya, South Africa and USA. Interestingly, Senegal and South Africa consider "Fight against poverty" in their energy security definition.

From an analysis of the criteria in Table 1, a number of common criterion defines energy security, namely: availability of energy resource supply, greater self-reliance/self-sufficiency rate, accessibility to fuel resources by all citizen, satisfies the energy demand at affordable/acceptable price, diversification of energy sources/suppliers, do not adversely affect the economic performance, without harming the environment, good quality energy supply, geopolitical concerns surrounding resource acquisition, and risks reduction/ risks management. The definitions of energy security as well as the parameters involved are broad and in most cases, qualitative. To help interpret this definition in quantitative terms for practical purposes would need "indicators". Presenting quantitative indicators would also help to compare its status in different countries, prioritise energy security issues, and more importantly develop energy policies/measures to address and improve energy security. Though few quantitative indicators (e.g., RPR, electrification rate, etc.) are available for many countries, there is lack of detailed indicators for many parameters. Furthermore, most energy security indicators are based on past data, and so there is no information on how these indicators would be in the future.

This paper addresses the above issues and presents quantitative indicators of energy security. This is based on a review of energy security indicators, which resulted in identifying 19 indicators that could be grouped under five themes. The quantitative values of these indicators were developed for Thailand and were based on historical data during 1986–2009 using published information by government and other sources. The indicators depicting the future energy security of Thailand were also analysed by considering three energy scenarios—current government policies and energy scenarios until 2030 studied by IEA [19], high economic growth and least cost energy system option studied by Watcharejyothin [20], and low carbon society scenario studied by Limmeechokchai [21]. A comparative study of the (future) indicators was carried out from a short- and a long-term perspective.

This paper has seven sections: Section 2 presents a review of the indicators to assess energy security, and Section 3 presents a summary of Thailand energy (current) polices. Then, Section 4 presents the energy security indicator assessment methodology and the future energy demand of Thailand based on the three energy scenarios (until 2030). Section 5 presents the developed

Table 1
The criteria that define energy security by various sources.
Source: APERC [8], Brown and Pound [9], ENDA [17], Energy Research Centre [14], EPPO [10], Goldemberg et al. [15], IEA [19], Karekezi et al. [16], Murakami et al. [12], TERI [18], and WEC [13].

No.	Criterion to define energy security	WEC	APERC	IEA	Brazil	India	Japan	Kenya	Senegal	South Africa	Thailand	USA
1	Availability of energy resource supply, greater self-reliance/self-sufficiency rate, Sustainable supply, accessibility by all citizen, accessibility to fuel resources	√	√	√	√	√	√	√		√	√	
2	Covering energy requirement/demand diversity	√	√	√	√	√	√		√		√	
3	Energy price-affordable price or acceptable price	√	√	√		√	√		√	√	√	
4	Diversification of energy sources, Diversification of import source countries/ suppliers		√				√	√		√	√	√
5	Not adversely affect the economic performance, Interactions among economic sectors	√	√				√		√	√	√	
6	Without harming the environment, Good quality energy supply			√					√	√	√	
7	Geopolitical concerns surrounding resource acquisition, risks reduction/risks management (transportation, domestic, supply interruption)		√	√			√				√	
8	Available in timely manner		√	√		√						
9	Fight against poverty								√	√		
10	Mixes in a cost effective manner-production cost reduction							√			√	
11	Prescribed confidence level considering shocks and disruptions			√		√						
12	Resilient energy system/withstanding threats/less vulnerable infrastructure			√								√
13	Securing energy supply for Social activities, defense and other purpose						√					√

energy security indicators (past and the future) of Thailand. Section 6 presents a comparative analysis of Thailand energy security indicators based on literature and present study. The concluding remarks are given in Section 7.

2. Energy security indicators

Indicators developed to quantify and illustrate energy supply and demand at country level have been developed by various institutions/organisations (European Commission (EC), European Environment Agency (EEA), Organization for Economic Co-operation and Development (OECD), International Energy Agency (IEA), Asia Pacific Energy Research Center (APERC), International Atomic Energy Agency (IAEA), World Energy Council (WEC), etc.). They describe the relation between the use of energy and human activity, as well as economical, social and environmental impacts of the energy market [11,22,23].

Fig. 1 shows the indicators used to assess energy security/ energy policy/energy for sustainable development. They are commonly used to measure and assess the possible energy scenarios [8,11–13,22,24–28], and are grouped in four dimensions: institutional, social, environment and economy. For example, the economy dimension has 12 indicators which are represented as ‘‘EC16: Diversity of supply of fuel types and suppliers’’. The theme ‘‘EC20: Level of energy import’’ has nine indicators. The energy intensity is aggregated with other indicators to form an aggregated energy indicator called ‘‘assessment index (AI)’’, ‘‘energy sustainability country index’’, ‘‘Energy Indicators for Sustainable Development (EISDs)’’, ‘‘*S*/*D* index’’, ‘‘Bollen’s indicator’’ and ‘‘oil vulnerability index (OVI)’’.

WEC [13] assessed energy polices by combining 46 indicators and developed the ‘‘assessment index (AI)’’. Energy security is a part of AI and is assessed using five indicators namely, diversity of energy supply, energy investment per total investment, capacity margin of electricity, stocks of oil (commercial and government owned), and net energy imports. AI is used to identify the best energy practices within a group of countries to achieve the goal of energy sustainability especially in terms of energy equity, energy security, and environmental compatibility. AI represents indicators concerning institutions, economy, social aspects, and the environment. This indicator is also used to represent the ranking of country within a cluster of countries. There are 5 country clusters: lower-income (< \$4000/year) net energy importers (13 countries), lower-income (< \$4000/year) net energy exporters (7 countries), fast-growth countries (31 countries), higher-income (> \$18,000/year) net energy exporters (8 countries) and higher-income (> 18,000/year) net energy importers (29 countries). Thailand is a member in the fast-growth countries and has the same rank as Croatia, Jordan, Latvia, Lithuania, Poland, South Africa, and Tunisia [13]. Since AI is presented on a yearly basis, the trend of a country's energy security performance could not be ascertained.

In 2010, WEC assessed the energy and climate policies by using 22 indicators and produced the ‘‘energy sustainability country index’’. Energy security is the part of this indicator which is assessed by using five indicators—energy consumption growth, ratio of energy production to consumption, wholesale margin on gasoline, diversity of electricity production, and dependence on and diversity of energy exports (for energy exporting countries), while oil reserve stocks is an indicator (for energy importers). These indicators are different from the WEC assessment in 2009, and the groups were changed as follows: GDP per capita greater than USD33,500 (Group A), GDP per capita between USD14,300 and USD33,500 (Group B), GDP per capita between USD6000 and USD14,300 (Group C), and GDP per capita lower than USD6000 (Group D). Thailand is in Group C, and is ranked 57th (out of 88 countries) [28].

UN Department of Economic and Social Affairs (UNDESA) published 30 indicators (Energy Indicators for Sustainable Development (EISDs)) on social, environment and economy related issues in 2005 [25]. These are used to assess the sustainable energy development performance focusing on energy conservation and efficiency policy. In the case of Thailand, a comparison between 1990 and 2000 considering before and after policy implementation shows that ‘‘the energy intensity remained fairly stable, but emissions quickly rebounded in 2000. There were distortions caused by the financial crisis in 1997–2000. However, the results show significant improvements in per capita and household incomes, access to, and affordability of modern energy services, especially for the poorest segments of the population’’ [29].

The Global Network on Energy for Sustainable Development (GNESD) analyzed energy security of Argentina, Brazil, Senegal, India, Kenya, South Africa, and Thailand at national and

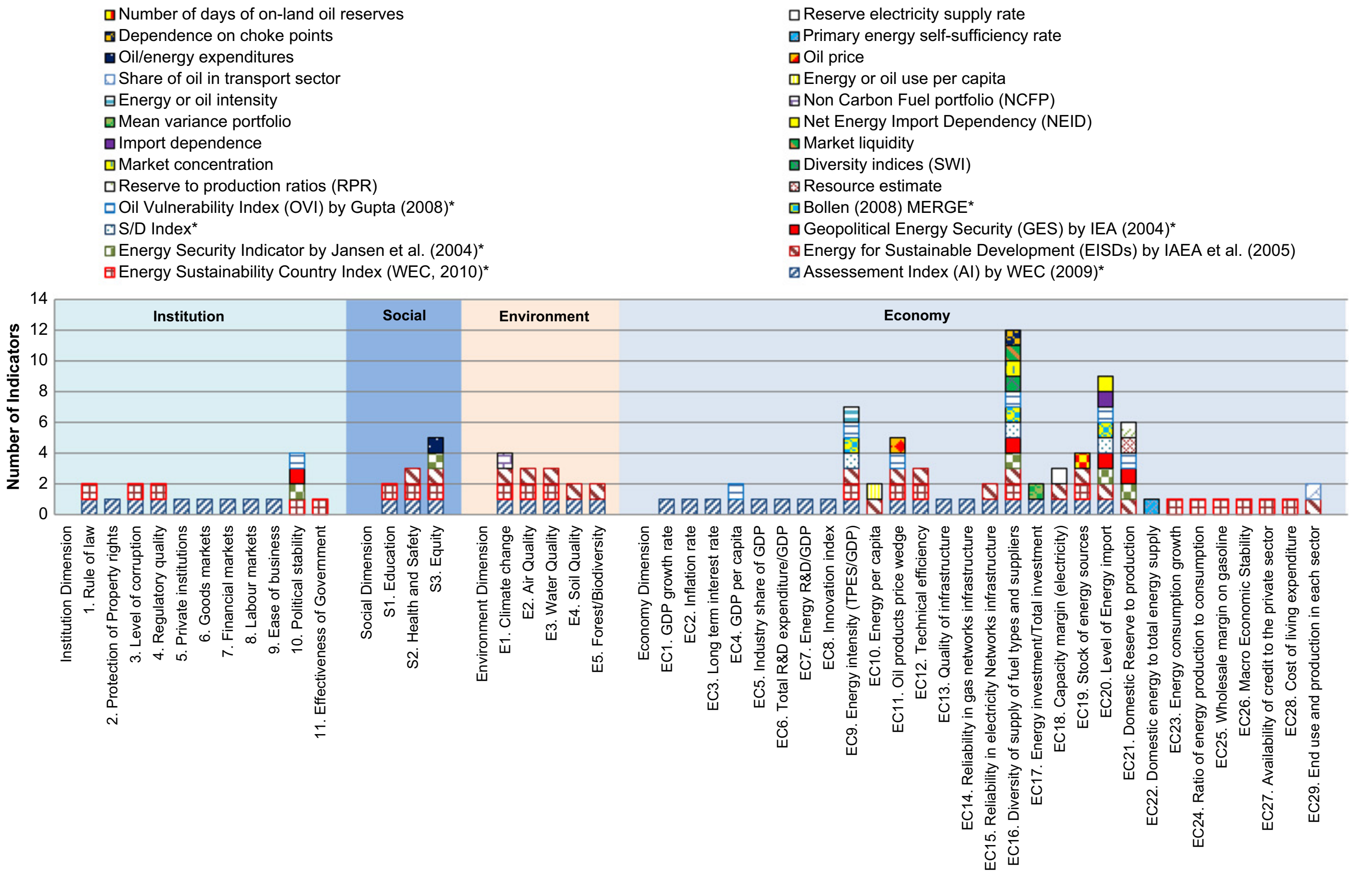

Fig. 1. Energy indicators in different dimensions. *Note* * it is an aggregated indicator.
Source: APERC [8], Grubb et al. [27], Gupta [24], IAEA [25], IEA [11], Jansen et al. [26], Kruyt et al. [22], Murakami et al. [12], WEC [13], and WEC [28].

household level. At national level, the indicators used were net energy import ratio (NEIR) which presents the energy import dependency, Shannon–Wiener index (SWI) and Herfindhal–Hirshman index (HHI), which presents the diversification of energy resources. Depletion of fossil energy reserves is given by reserve-to-production ratio (*R*/*P* ratio). The economic implications of energy imports were assessed through two indexes: Vulnerability index I: Expenditure on energy imports per GDP and Vulnerability index II: Expenditure on energy imports per total export earnings. At the household level, GNESD used five indicators for analyzing energy security. These were household expenditures on energy, fuels, by income groups, and access to electricity, and fuels used for cooking. In Thailand, lower income group (earning less than 3000 Baht/month) have energy expenditure of 17% of their income, while the 30,000 Baht/month income group's share is only 5%. In addition, the energy demand in the residential sector was driven by increasing urban population and the level of income [30,31].

APERC [8] used five indicators to analyze energy security. These were diversification of primary energy demand (DoPED), net energy import dependency (NEID), non-carbon intensive fuel portfolio (NCFP), net oil import dependency (NOID), and middle east oil import dependency (MEOID) [8]. Selvakumaran and Limmeechokchai [32] used these indicators to assess energy security for Great Mekong Sub-region (GMS) countries (Thailand, Cambodia and Laos PDR). The results show that though Thailand has the most diversified energy supply system, it has the worst energy security in terms of oil compared to Laos PDR and Cambodia.

The Institute of Energy Economics, Japan (IEEJ) used seven indicators to analyze the energy security of France, Germany, United Kingdom, United States, China, Japan and South Korea. The indicators were primary energy self-sufficiency rate, degree of diversification of energy import source countries, degree of diversification of energy sources, degree of transportation risk management, degree of domestic risk management, degree of demand conservation, and degree of supply interruption risk management [12].

Fig. 1 shows that most studies on indicators did not consider the political stability of energy exporter as high priority of energy security assessment (only three indicators are concerned with this issue). Some indicators reflect the energy consumption of the economic structure. Other energy security indicators represent mostly the economic perspective, and focus on four major themes: diversity of fuels types/suppliers (12 indicators), energy import (9 indicators), energy intensity (7 indicators), reserve to production ratio (6 indicators) and oil price (5 indicators). This clearly indicates that indicators that consider other perspectives are also needed to assess energy security, such as political stability, equity and climate change.

3. Thailand energy policy

The energy policy of Thailand stated by the then Prime Minister to the national assembly on 29 December 2008 has the following five major themes [10]:

- "Energy security policy: Developing energy sources in the country for greater self-reliance in order to increase energy stability and to meet sufficient demand.
- Renewable and alternative energy policy: Encouraging the production and utilization of renewable energy in all sectors.

- Energy price policy: Supervising and maintaining energy price at appropriate, stable and affordable levels.
- Encourage energy conservation in all sectors through energy conscience campaign and promote effective energy usage with incentives.
- Encourage energy exploration and usage which reduces the effect to the environment through public participation by setting various standards."

The Thai government had launched the Energy Conservation Promotion Act B.E. 2535 in 1992 and initiated programs on energy conservation, energy efficiency, demand side management (DSM) Program, Renewable Energy and Rural Industries Programs, Research and Development Programs, Industrial Liaison Program, the Energy Conservation Promotion Fund (ENCON Fund), Energy Service Company (ESCO) Energy standards, etc. The energy conservation plan had three phases: phase I during 1995–1999, phase II during 2000–2004 and phase III during 2005–2011 [33,34]. The efficiency measures are expected to reduce energy intensity by 25% and energy saving of 33.4 Mtoe by 2030 [35].

The renewable energy roadmap (15 years plan during 2008–2022) launched in January 2009 has renewable energy target at the end of 2022 to be 14% of the final energy consumption (13.7 Mtoe) for heat, power and biofuels consumption. In addition, an NGV target (6.1 Mtoe) in the transportation sector is aimed to reduce oil demand/import. Through these measures, the alternative energy will account for 20.3% of the total final energy consumption in 2022 [35,36].

The power development plan (PDP 2010) is revised yearly by updating the framework of power plants based on the actual growth rate of electricity demand coupled with the country's economic situation. It plans for a total power generation capacity of 52,890 MW in 2030. This plan includes the 15 years renewable energy plan and energy efficiency measures of using fluorescent lamp T5 instead of T8 (it would save 240 MW or 1170 GW h in 2030), and 5000 MW nuclear power plants. In addition, the maximum power purchase from the neighboring countries should be less than 25% of total generation capacity. The CO_2 emission of power sector is expected to reduce from 0.482 tCO_2/MW h in 2010 to 0.368 tCO_2/MW h in 2030, resulting in CO_2 emission reduction by 31% in the power sector [37–39].

By implementation of the policies, programmes and activities, the government aims to enhance the energy security of the country. Furthermore, the Energy Policy and Planning Office (EPPO) has a strategy that all citizens have the right to participate in energy policy development [40]. Therefore, presenting the results of policies, programmes and activities in terms of quantitative (and qualitative) indicators would help illustrate the status and nature of the energy security situation, and so useful for supporting the procedures of decision making on energy policy development.

4. Methodology to assess energy security indicator for Thailand

This section describes the methodology used to assess the energy security of Thailand during 1986–2030. Section 4.1 presents the selection process of the energy security indicators. Section 4.2 presents the data required for the estimation energy security indicators during 1986–2009, while Section 4.3 presents the data for calculating the indicators during 2010–2030 for the three scenarios. Section 4.4 compares the methodology of energy security assessment.

4.1. Selection of energy security indicators

Since there is no universally accepted definition of energy security, indicators to assess energy security were identified that comes under the common criteria of energy security. A compilation of the definitions of energy security by various sources are listed in the appendix (Table A.1). The most common criteria presented in the definition were then used to constitute energy security, and these are presented in Table 1. Using the basic definition of energy security (No. 1–7 of Table 1), indicators were identified and selected to quantify energy security. This resulted in 19 indicators, which are listed in Table 2. These 19 indicators can be clustered into five major groups: energy demand, availability of energy supply/resources, environmental concerns, energy market, and energy price/cost/expenditure, as shown below.

- **Energy demand** represents the energy intensity (energy use per GDP), energy use per capita, and related issues (It also considers one major energy resource and one sector which is country dependent—oil and transportation in the case of Thailand).
- **The availability of energy supply resources** is represented by resources estimate and reserve to production ratio (RPR). Diversification of energy supply resources is represented by Shannon–Wiener index (SWI).
- Non-carbon intensive fuel portfolio (NCFP) and CO_2 emission are used to present the energy consumption and its relation to **the environment dimension**.
- **Energy market** parameters are represented by energy import, energy import dependency (NEID), geopolitical market concentration risk (GMC), market liquidity (ML), Geopolitical Energy Security (GES) and oil vulnerability index (OVI).
- Finally, indicators related to **energy price/expenditure,** are oil expenditure per GDP and final energy cost per GDP.

These clustered groups of indicators reflect the energy security issues of the overall energy system, and thus takes into consideration the generation, conversion, utilization and impact. Such a cluster will also assist policy makers to evaluate and assess measures/policies on demand side, supply side and/or others. For example, the renewable energy roadmap of Thailand (15 years plan during 2008–2022) would throw light on improvement on energy security of supply and reduction the environment impacts. Moreover, it could help in the alternative options to diversify energy resources. However, these measures by themselves may not reduce the total energy consumption (of demand side), or improve the efficiency of energy system (of supply side) and/or reduce energy expenditure. Therefore, policy makers need additional measures/policies to address these issues. The LPG, NGV and diesel price subsidies would help reduce the energy expenditure. But, price subsidy measure neither improves the RPR of these fuels nor reduces CO_2 emission. As a result, policy makers must consider all causes and effects of their policies/measures by using all above indicators as a tool.

The definition and details of these selected energy security indicators are given in Table 2, and the equations to calculate them are presented in the appendix (Tables A.2–A.6). This list of indicators selected and further discussed are those that satisfy the common criteria used to define energy security, and so do not encompass all the social and institutional dimension in Fig. 1 and all the criterion listed in Table 1.

The common criterions reflected by these selected indicators are availability of energy resource supply, greater self-reliance/self-sufficiency rate, accessibility to fuel resources by all citizen, satisfies the energy demand at affordable/acceptable price, diversification of energy sources/suppliers, do not adversely affect the

Table 2
Selected indicators to assess energy security.
Source: AIT [31], APERC [8], Grubb et al. [27], Gupta [24], IEA [11], Jansen et al. [26] and Kruyt et al. [22].

No.	Indicator	Definition	Source	Reflect criterion of energy security in Table 1
Energy demand				
1	Energy and oil intensity	The ratio of energy/oil consumption to GDP	Kruyt et al. [22]	Criteria 2 and 5
2	Energy and oil use per capita	The ratio of energy/oil consumption to country's population	Kruyt et al. [22]	Criteria 2
3	Share of transport sector	The share of energy consumption in transportation sector per total final energy consumption	Kruyt et al. [22]	Criteria 2
4	Share of oil use in transport sector	The share of oil use in transportation sector per total oil consumption in all sector	Kruyt et al. [22]	Criteria 2
The availability of energy supply resources				
1	Resource estimate	Quantity and likelihood of occurrence of fossil resources	Kruyt et al. [22]	Criteria 1
2	Reserve to production ratios (RPR)	Resource estimates and production figures (at country or global level)	Kruyt et al. [22]	Criteria 1
3	Diversity indices (Shannon–Wiener index SWI)	Shares of fuel in total primary energy supply or shares of suppliers in import	Grubb et al. [27], AIT (2009)	Criteria 4
Environmental concerns				
1	Non carbon incentive fuel portfolio (NCFP)	The total of non-carbon fuel (hydro, nuclear, new and renewable energy) consumption per total primary energy supply	APERC [8]	Criteria 6
2	CO_2 emission	The estimation of annual CO_2 emission of all fossil fuel (oil, natural gas, and coal) consumption	APERC [8]	Criteria 6
Energy market				
1	Energy import	Quantity of energy import per total primary energy supply	Kruyt et al. [22]	Criteria 4 and 7
2	Net energy import dependency (NEID)	The share of energy import weighted with its fuel diversity	Kruyt et al. [22], APERC [8]	Criteria 4 and 7
3	Geopolitical market concentration risk (GMC)	The qualitative of political stability of energy supplier countries in world market	IEA [11]	Criteria 4 and 7
4	Market liquidity (ML)	The ratio of world oil supply to the net oil import of a country	Gupta [24]	Criteria 4 and 7
5	Energy security indicator	The aggregated indicator accounting for energy imports, political stability in producing regions and for the proven regional reserves with respect to the annual production in the region concerned	Jansen et al. [26]	Criteria 1 and 7
6	Geopolitical Energy Security (GES)	The aggregated indicator deals with the physical availability, political risk of exported countries and weighted by the fuel's share in primary energy supply	IEA [11]	Criteria 1 and 7
7	Oil vulnerability indicator (OVI)	The aggregated index of oil vulnerability based on seven indicators: (1) the ratio of value of oil imports to GDP; (2) oil consumption per unit of GDP; (3) GDP per capita; (4) oil share in total energy supply; (5) ratio of domestic reserves to oil consumption; (6) exposure to geopolitical oil supply concentration risks as measured by net oil import dependence, diversification of supply sources, political risk in oil-supplying countries, and (7) market liquidity	Gupta [24]	Criteria 1, 2, 4 and 7
Energy price/cost/expenditures				
1	Oil/energy expenditures	The annual energy/oil expenditure per GDP of a country	Kruyt et al. [22]	Criteria 3 and 5
2	Retail petroleum products price	The retail petroleum products' price	Kruyt et al. [22]	Criteria 3 and 5
3	World oil price	The world crude oil price	Kruyt et al. [22]	Criteria 3 and 5

economic performance, without harming the environment, good quality energy supply, geopolitical concerns surrounding resource acquisition, and risks reduction/risks management. These are criteria 1–7 in Table 1.

Criteria 8–13 in Table 1 namely, available in timely manner, fight against poverty, mixes in a cost effective manner-production cost reduction, prescribed confidence level considering shocks and disruptions, resilient energy system/withstanding threats/ less vulnerable infrastructure, securing energy supply for social activities, defense and other purpose are not presented in this study.

4.2. Data for energy security indicators calculation

The quantitative energy security assessment is presented using selected 19 energy security indicators. For the indicators during the period 1986–2009, the data on energy proven reserves [41,42], energy consumption by sector [43–52], energy production

[53–55], energy import/export [56], electrical power [57–60], gross domestic production (GDP), energy price, and energy expenditure was collected from annual reports, official reports and statistical database published by Ministry of Energy, Thailand, Department of Alternative Energy Development and Efficiency (DEDE) and Energy Policy and Planning Office (EPPO) [61–71].

Data on energy efficiency, energy conservation, and renewable energy projects in Thailand is published by DEDE [72]. Countries from where petroleum products, crude oil, and natural gas are imported are reported in "Oil and Thailand annual report" by DEDE [61–65] and the political risk rating of import source countries is reported by International Country Risk Guide [73]. The default values of emission factors of crude oil, natural gas and coal published by the Intergovernmental Panel on Climate Change (IPCC) [74] were used to quantify the annual CO_2 emission.

4.3. Thailand energy scenarios during 2010–2030

To estimate the energy security indicators of Thailand during 2010–2030, results from studies conducted to forecast Thailand's energy consumption were used. To provide a comprehensive picture on how the energy security situation would look like in the future, three scenarios were considered:

- "High economic growth and least cost option (HEG&LC)" Scenario by Watcharejyothin [20]. This study presents Thailand's energy consumption during 2000–2035. The assumptions used for this scenario are: GDP annual average growth rate is 5.1% during 2000–2035 resulting in GDP of 11,000 billion Baht (constant 1988 price) in 2030. This study uses the MARKet Allocation (MARKAL) model, which gives the least cost option pathway of energy system based on the projected economic growth. In 2030, energy consumption would be more than 300 Mtoe, and the main resources will be coal (151 Mtoe), oil (74 Mtoe), renewables (31 Mtoe), and natural gas (30 Mtoe). Nuclear power will account for 14 Mtoe, power imports 5 Mtoe, and hydropower 2 Mtoe. The data (Table 3) of primary energy consumption by fuel, energy domestic production by fuel, energy import by fuel, population and GDP for the period 2010–2030 from this scenario study were used to calculate the energy security indicators for this scenario.
- The scenario "low carbon society (LCS)" is based on the study by Limmeechokchai et al. [21], which used the Extended Snapshot Tool (ExSS) for energy projection during 2005–2030. This scenario assumes the GDP average growth rate to be 3.8% and the GDP will be 14,500 billion Baht (constant price 1988). They considered current energy policies, measures (energy conservation and energy efficiency) and the Power Development Plan (PDP) 2010. Their study focused on the pathway of LCS, which relied on secondary and tertiary industry instead of high energy intensive industry. Moreover, additional alternative measures to reduce CO_2 emission were selected based on cost effective projects. Their result shows that Thailand could reduce CO_2 emission by 42% and save energy by 31% in 2030 from business as usual case. The main energy resource of LCS in 2030 would be oil (49 Mtoe) and renewables (41 Mtoe), while coal and natural gas consumption would contribute 28 and 28 Mtoe, respectively. Besides, 7 Mtoe of hydro power and 4 Mtoe of nuclear energy would be the other major sources. However, their study did not consider the energy import and domestic production by fuel. Therefore, the domestic oil production would be at 11.95 Mtoe/year during 2010–2011 and at 12.45 Mtoe/year during 2012–2013 as reported in the action plan of EPPO [40]. In 2014, the domestic production is assumed at 12.45 Mtoe/year (same as in 2013). At this rate of domestic crude oil production, the domestic oil production would be 0.6 Mtoe in 2015 due to the depletion of domestic crude oil proven reserve. The domestic gas production was assumed at 90% of natural gas consumption during 2010–2030. This assumption was made to find the impact of increasing domestic production of natural gas from 71% to 76% during 2004–2009 [66]. The average coal demand growth rate of LCS scenario is 3.2% per year, but the domestic coal production was assumed at 2% annual growth rate from 2009, due to the low quality of domestic coal and public concern on coal use, and the import of high quality of coal is an option [19]. The results of energy consumption and GDP for this scenario given in Table 4 were used to calculate the energy security indicators during 2010–2030 for the LCS scenario.
- The third scenario "current policy (CP)" by IEA [19] used the World Energy Model. The Thailand's energy projection in 2030 was simulated based on GDP annual average growth rate of 3.3% (during 2007–2030). A slower growth of economy was expected in their analysis, due to the financial crisis [19]. The current energy policy and measures in Thailand (excluding PDP 2010) were taken for the projection. The results show that in 2030, GDP will reach 8900 billion Baht (constant 1988 price) and the energy consumption will be 174 Mtoe. The main energy resources would be oil (65 Mtoe) followed by coal, natural gas and renewable energy, which will account for 39,

Table 3
Input for the high economic growth and least cost energy system option scenario study.
Source: Watcharejyothin and Shrestha [20].

Socio-economic-energy parameters	Unit	2005	2010	2015	2020	2025	2030
Population	Million	62	63	64	65	65	66
GDP current price	Billion Baht	7093	8900	11,400	14,600	18,700	23,600
GDP at 1988 constant price	Billion Baht	3858	4196	5,375	6,884	8,817	11,128
GDP at 1988 constant price and 2000 exchange rate	Billion USD	96	104	134	171	220	277
GDP growth rate	%	4.6%	−1.6%	4.6%	4.6%	4.6%	4.3%
Total primary energy consumption	Mtoe	93	120	150	194	246	307
Domestic oil production	Mtoe	8.8	2.9	1.4	1.4	1.4	1.4
Domestic gas production	Mtoe	20.6	28.1	12.1	7.4	5.0	2.5
Domestic coal production	Mtoe	6.0	6.0	6.9	8.2	9.1	9.5
Domestic hydro production	Mtoe	0.3	1.5	1.5	1.5	1.5	1.5
Domestic renewable energy	Mtoe	17	22	33	35	36	31
Domestic nuclear power	Mtoe	–	–	–	7	10	14
Imported oil	Mtoe	35	28	39	50	59	73
Imported gas	Mtoe	8	15	29	29	26	27
Imported coal	Mtoe	5	15	22	50	93	142
Imported hydro power	Mtoe	0	1	5	5	5	5

Note: Exchange rate is 40.16 Baht/USD in 2000.

Table 4
Input and assumptions for the low carbon society scenario study.
Source: Limmeechokchai et al. [21] and EPPO [40].

Socio-economic-energy parameters	Unit	2005	2010	2015	2020	2025	2030
Population	Million	62	63	64	66	67	69
GDP current price	Billion Baht	7093	12,574	17,131	21,688	26,245	30,802
GDP at 1988 constant price	Billion Baht	3858	5,929	8,077	10,226	12,375	14,523
GDP at 1988 constant price and 2000 exchange rate	Billion USD	96	148	201	255	308	362
GDP growth rate	%	4.6%	39.1%	5.6%	4.4%	3.6%	3.0%
Total Primary Energy Consumption	Mtoe	93	90	106	122	139	156
Domestic oil production	Mtoe	8.8	11.9	0.6	–	–	–
Domestic gas production	Mtoe	20.6	20.4	21.6	22.9	–	–
Domestic coal production	Mtoe	6.0	4.9	5.4	5.9	6.5	7.2
Domestic hydro production	Mtoe	0.3	1.3	1.3	1.3	1.3	1.3
Domestic renewable energy	Mtoe	17.0	17.6	23.3	29.1	34.8	40.6
Domestic nuclear power	Mtoe	–	–	–	0.7	2.6	4
Imported oil	Mtoe	35.5	21.6	36.8	41.2	45.1	48.9
Imported gas	Mtoe	7.7	2.3	2.4	2.5	26.9	28.3
Imported coal	Mtoe	5.3	9.9	12.6	15.2	17.8	20.3
Imported hydro power	Mtoe	0.4	0.4	1.7	2.8	4.1	5.3

Note: Net import = demand − production − export, domestic gas production was assumed 90% of natural gas consumption, domestic coal production was assumed 2% growth rate from 2009.

Table 5
Input and assumptions for the current policy scenario study.
Source: IEA [19] and EPPO [40].

Socio-economic-energy parameters	Unit	2005	2010	2015	2020	2025	2030
Population	Million	62	65	66	67	68	70
GDP current price	Billion Baht	7093	9397	11,054	13,002	15,294	17,989
GDP at 1988 constant price	Billion Baht	3858	4692	5,519	6,492	7,636	8,982
GDP at 1988 constant price and 2000 exchange rate	Billion USD	96	117	137	162	190	224
GDP growth rate (%)	–	4.6	10.1	3.3	3.3	3.3	3.3
Total primary energy Consumption	Mtoe	93	110	120	135	153	174
Domestic oil production	Mtoe	8.8	11.9	0.6	–	–	–
Domestic gas production	Mtoe	20.6	26.6	28.5	–	–	–
Domestic coal production	Mtoe	6.0	4.9	5.4	5.9	6.5	7.2
Domestic hydro production	Mtoe	0.3	0.8	0.8	0.9	1.0	1.0
Domestic renewable energy	Mtoe	17	20	23	26	29	31
Domestic nuclear power	Mtoe	–	–	–	–	–	–
Imported oil	Mtoe	35	31	45	51	58	65
Imported gas	Mtoe	8	3	3	34	37	38
Imported coal	Mtoe	5	11	14	17	23	32
Imported hydro power	Mtoe	0.4	–	–	–	–	–

Note: Net import = demand − production − export, domestic gas production was assumed 90% of natural gas consumption, domestic coal production was assumed 2% growth rate from 2009.

38 and 31 Mtoe, respectively. In this scenario, the domestic production of crude oil, natural gas and coal were assumed to be the same as the LCS scenario. The data used to calculate the energy security indicators are given in Table 5.

A summary of population, GDP and total primary energy supply during 1986–2030 for the three scenarios are given in Fig. 2. The energy security indicators, namely, energy intensity, energy per capita, transportation share, RPR of coal, oil and natural gas, energy resource diversification, non-carbon incentive fuel portfolio, CO_2 emission and energy import dependency of these three scenarios during 2010–2030 are presented in Figs. 3–10. The results are further discussed in Section 5.

4.4. *Comparison of ESI methodologies*

Table 6 presents a comparison of the indicators from various studies. The key issues are:

- **Indicator selection and number of indicators**: The number of indicators and indicators used in the analyses vary widely. IEEJ selected their indicators based on the concept of energy security and critical areas need to be focused. WEC identified a long list of indicators to broadly examine the effective policies and evaluate their effects. GNESD selected the indicators at national level and household level. APERC selected indicators which reflect the importance and potential risks. In this study, the assessment was done by selecting the common indicators which represents the common criteria of energy security definition.
- **Countries studied:** The countries considered by the studies also differ. For example, IEEJ selected 7 countries for comparison, while WEC assessed 88 countries (separated in 5 groups of countries). GNESD used the same list of indicators to guide seven countries (including Thailand).
- **Level of analysis:** Most analyses were done at national level and comparison made among the group of countries, except for the GNESD study where the analysis was conducted at national and at household level.
- **Time frame used:** the period of time varied based on the objectives and scope of research. Ten year averages (1970s, 1980s, 1990s and 2000s) was considered by IEEJ. WEC presented the trends of (some) indicators during 1999–2006 and the aggregated indicator in 2006. GNESD analysed the energy

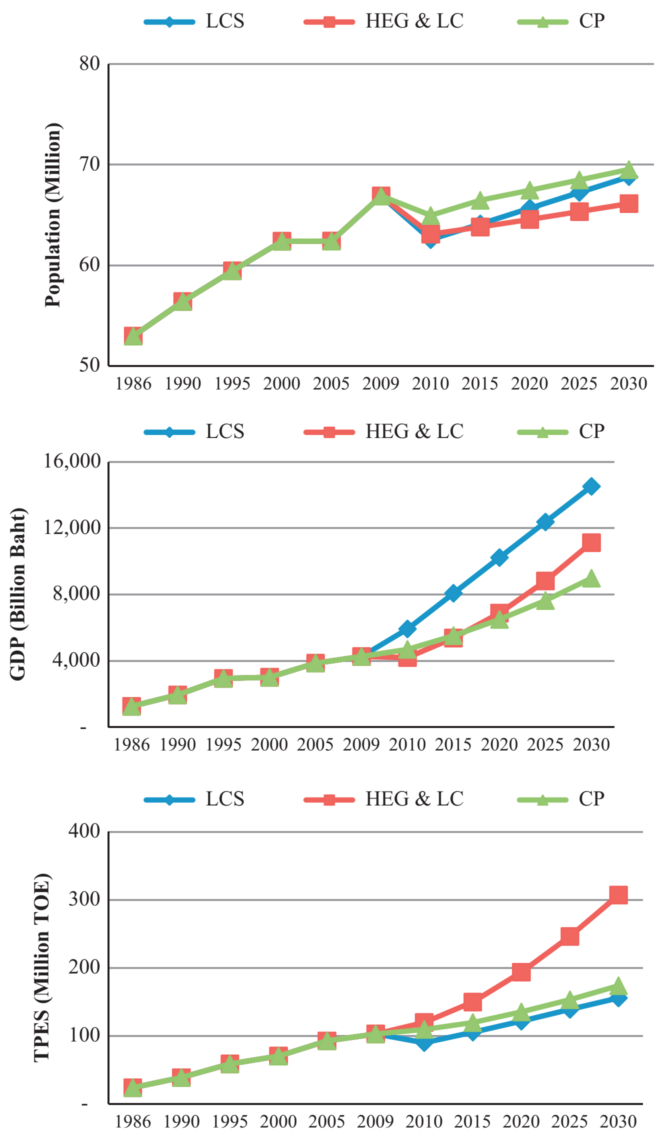

Fig. 2. Thailand population, GDP and total primary energy supply 1986–2030.

security situation from 2002 to 2006. APERC presented a comparison between 2004 and 2030. UNDESA analysed the trends during 1981–2000.

- **Scenario analysis:** Among the past studies, only the study by APERC presented the future ESI (for 2030).

The indicators developed in this paper could be used to assess the energy security at national (and could be expanded at provincial) level. These are based on the common criteria of energy security definition, and have been demonstrated for Thailand for a time period 1986–2030. For the period 2010–2030, three energy scenarios have been considered, which helps to illustrate the energy security for various energy use pathways.

5. Thailand's energy security indicators 1986–2030

Based on the data and the assessment methodology discussed in the earlier sections, the nineteen indicators categorized into five sets were estimated for Thailand. The indicators for the period 1986–2009 were based on actual data, while those for the period 2010–2030 were based on the outputs of the three

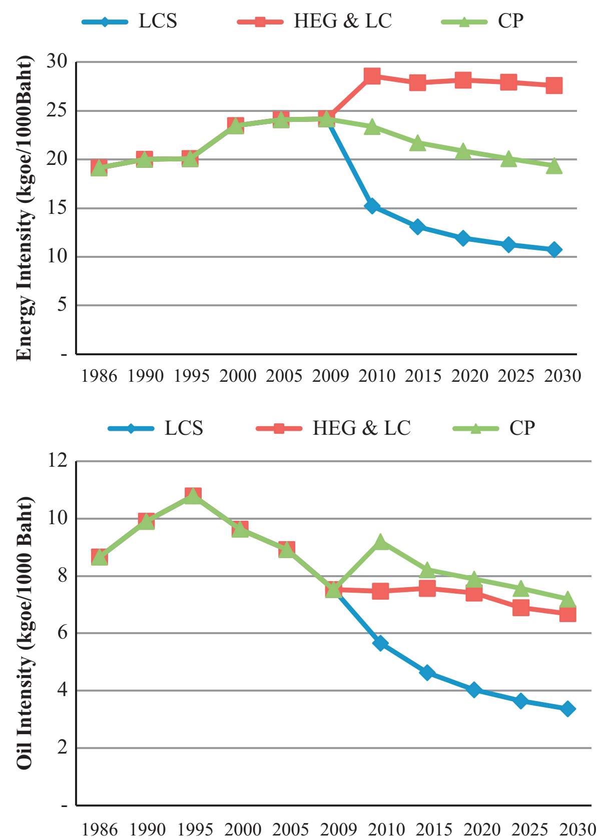

Fig. 3. Energy and oil intensity 1986–2030.

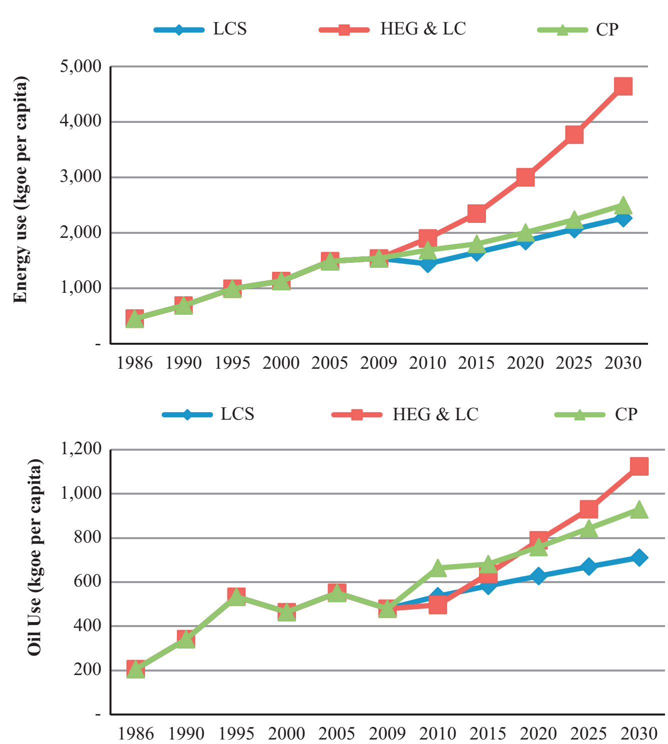

Fig. 4. Energy and oil use per capita 1986–2030.

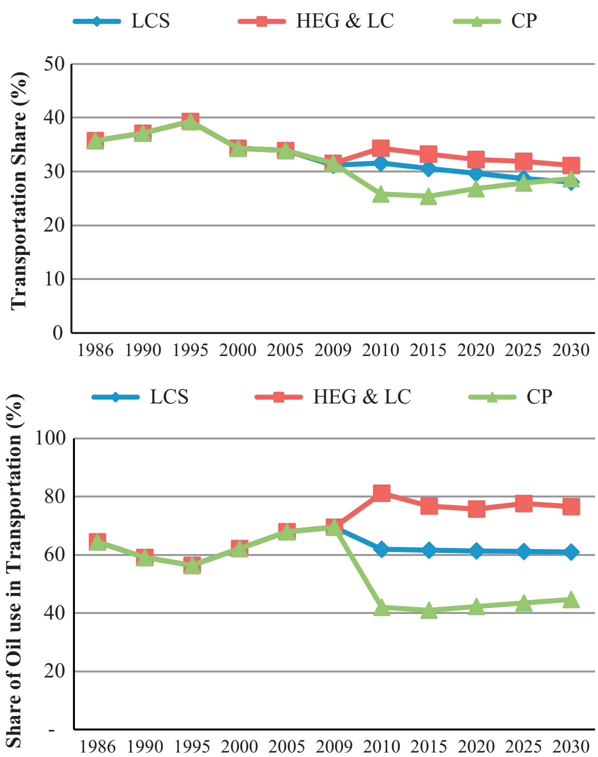

Fig. 5. Transportation share and share of oil in transportation sector 1986–2030.

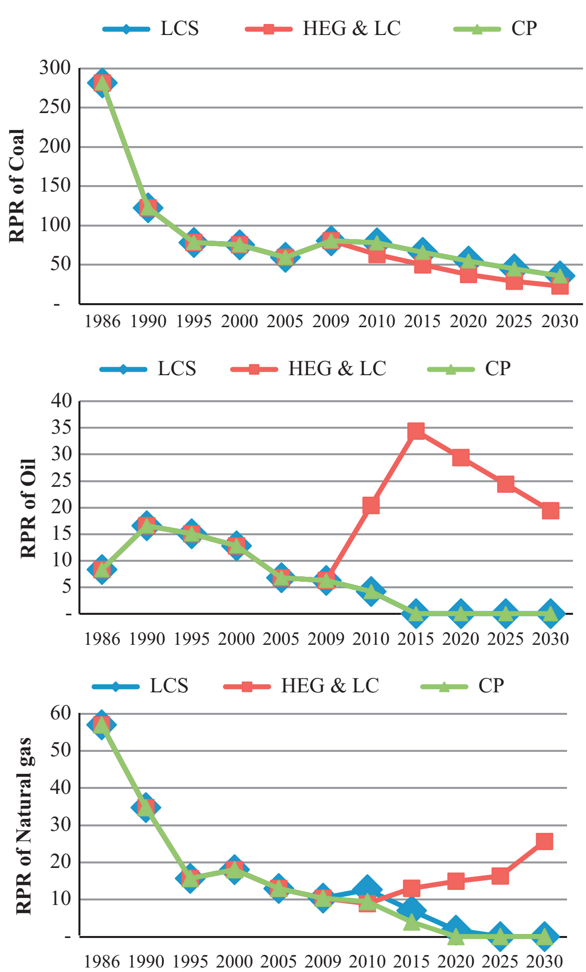

Fig. 6. RPR of coal oil and natural gas 1986–2030.

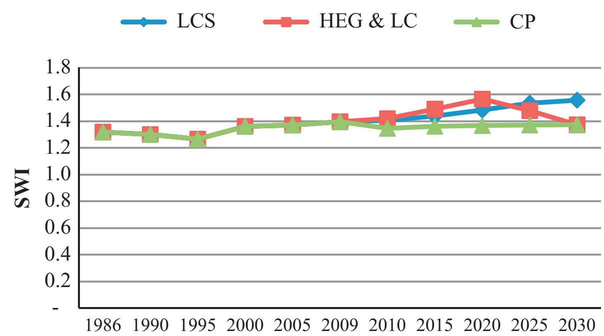

Fig. 7. Energy resource diversification (SWI) 1986–2030.

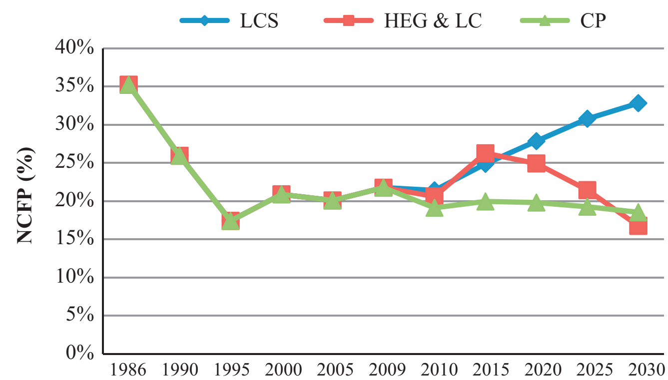

Fig. 8. Non-carbon incentive fuel portfolio (NCFP) 1986–2030.

energy scenarios discussed in Section 4. The quantitative values of these indicators are presented below and summarised in Table 7.

5.1. Energy demand

The demand side energy use is presented in terms of energy intensity, energy consumption per capita, and the role of one major energy use sector (transportation) and one important energy source (oil).

5.1.1. Energy intensity (EI) and oil intensity (OI)

The energy intensity increased from 20 kgoe per 1000 Baht in 1986 to 25 kgoe per 1000 Baht in 2009 (Fig. 3). During the period 2010–2030, CP and LCS scenarios show improvement in energy intensity as it is expected to be lower than 20 kgoe per 1000 Baht for CP, and 10 kgoe per 1000 Baht for LCS in 2030. During this period, HEG&LC's energy intensity would be stable at 28–29 kgoe per 1000 Baht during 2010–2030.

Considering the role of oil as the major primary source, the oil intensity indicator was also calculated. The oil intensity increased from 8 to 11 kgoe per 1000 Baht during 1986–1995, and then decreased to under 8 kgoe per 1000 Baht in 2009. In the LCS scenario, oil intensity will be lower than 4 kgoe per 1000 Baht in 2030, while in the CP scenario, it would reduce to 7 kgoe per 1000 Baht. HEG&LC presents a constant oil intensity at 8 kgoe per 1000 Baht during 2010–2020, and a slight reduction to 7 kgoe per 1000 Baht during 2025–2030.

5.1.2. Energy consumption per capita and oil per capita

Thailand's energy consumption per capita increased significantly (around threefold) from 432 kgoe in 1986 to 1540 kgoe in 2009. In addition, oil consumption per capita increased from 200 kgoe per capita in 1986 to 534 kgoe per capita in 1995, and then varied within a range of 450–600 kgoe per capita during

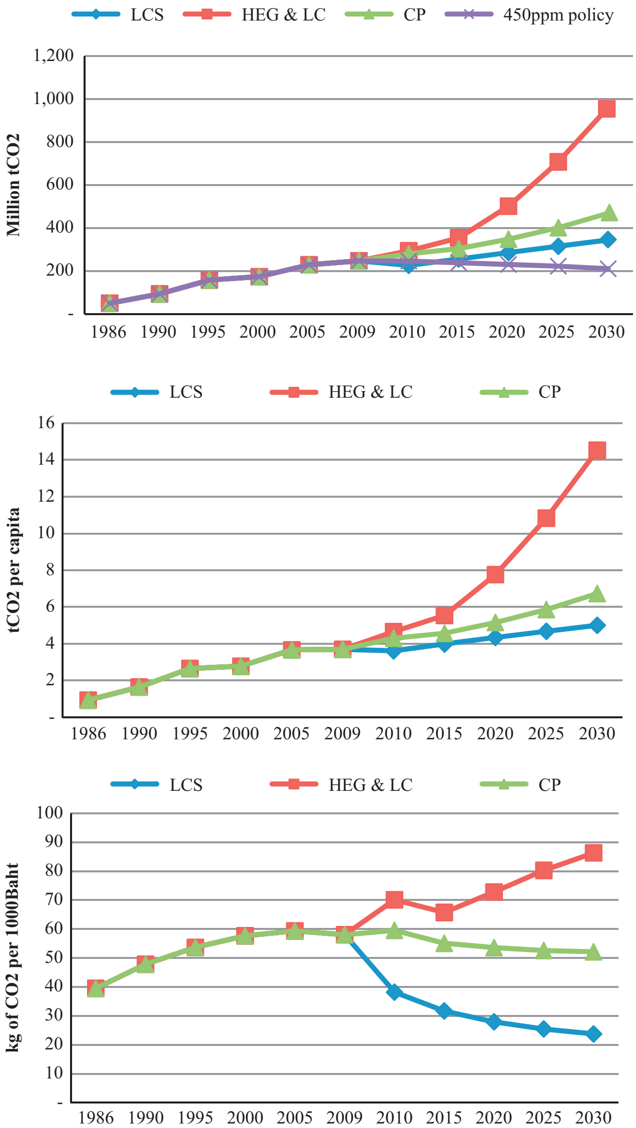

Fig. 9. CO_2 emission, CO_2 per capita and CO_2 per GDP 1986–2030.

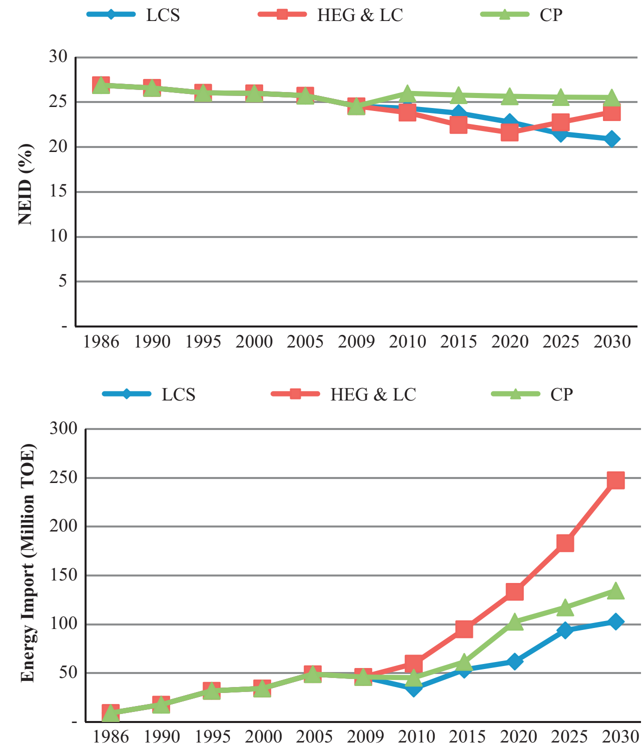

Fig. 10. Net energy import dependency (NEID) and Energy Import 1986–2030.

1996–2009. As shown in Fig. 4, energy use per capita will reach 2270 kgoe per capita in 2030 in the LCS scenario, and to 2500 kgoe per capita in the CP scenario. HEG&LC scenario predicts an exponential increase of energy consumption to 4642 kgoe per capita in 2030. The oil use per capita in the LCS and CP scenarios would be 700 and 900 kgoe, respectively, while the HEG&LC scenario presents the highest oil use per capita at 1100 kgoe in 2030.

5.1.3. *Transportation sector*

Transportation sector played an important role to drive the growth of economy with more than 30% share of total final energy consumption during 1986–2009 as shown in Fig. 5. Its highest share was 40% in 1995. The future trend of this share would be a slight reduction to 29% in the LCS scenario in 2030. In the HEG&LC pathway, this would increase in the short term during 2010–2015 to around 34%, and then decrease to 31%. In contrast, the CP scenario presents a significant decrease in short term (2010–2015) to around 25%, and then it would increase to 29% in 2030.

Fig. 5 also shows that the share of oil use in transportation sector varied between 50% and 70% of the total oil used in all sectors during 1986–2009. The results of fuel substitution by NGV, LPG and biofuels (biodiesel and gasohol) in the CP scenario would reduce the share of oil use in transportation sector to 40% during 2010–2030. The LCS scenario presents a constant share at 60%, and in the HEG&LC scenario, it would increase to 80% during 2010–2030.

The above four energy security indicators (ESIs) clearly indicate the rising energy demand in Thailand. This raises concern regarding energy security (of supply) in the long term and at the same time the need to ensure continuous economic growth.

5.2. *The availability of energy resources*

The supply side energy information is presented in terms of energy reserves and its diversification trend.

5.2.1. *Resources and reserves*

At the end of 2009, Thailand had proved oil reserves of about 180 million barrels (25 Mtoe), while natural gas and condensate proved reserves were 0.3 trillion m^3 (278 Mtoe) and 255 million barrels (34 Mtoe), respectively. Thailand's proved lignite reserves were 1181 Mt (384 Mtoe). At current domestic production rate, crude oil, condensate, natural gas and lignite would be available for 3, 8, 10 and 67 years, respectively [75].

In 2030, the availability of coal resources would be reduced to less than 36 years in the LCS and CP scenarios, while in the HEG&LC scenario, it would be only 23 years. The trend of reserves is shown in Fig. 6. HEG&LC scenario shows an improvement in the availability of energy reserves (oil and natural gas) providing for their longer utilization. It should be noted that EPPO has set the target benchmark of 30 years RPR to ensure that there will be no energy shortage in Thailand [40]. However, the three energy scenarios indicate that this target will not be realized.

Table 6
Comparison of energy security assessment.

No.	Criteria	Organizations						
		The Institute of Energy Economics, Japan (IEEJ) IEEJ (2011)	World Energy Council (WEC) [28]	World Energy Council (WEC) [13]	The Global Network on Energy for Sustainable Development (GNESD) [18]	Asia Pacific Energy Research Center (APERC) [8]	UN Department of Economic and Social Affairs (UNDESA) [25]	Present study
1	Indicator selection	Selected indicators are based on the concept of energy security	Selected indicators cover energy sustainability and the political, social, and economic attributes of countries	Selected indicators broadly examines the effective energy and climate policies and their effects	Selected indicators are based on the concept of energy security	Selected indicators reflect the importance and potential risks in terms of primary energy sources, associated with energy portfolio decisions	Set of indicators reflect the important issues within the context of sustainable development	Selected indicators are based on commonly used criteria of energy security definition
2	Number of indicators selected	7 indicators	5 indicators (22 indicators were used to develop an aggregated indicator)	5 indicators (46 indicators were used to develop an aggregated indicator)	6 indicators at national level and 5 indicators at household level	5 indicators	2 indicators for energy security (out of total 30 indicators for assessing EISDs)	19 indicators
3	Countries studied	7 countries (France, Germany, United Kingdom, United States, China, Japan and South Korea)	88 countries clustered by GDP per capita	88 countries clustered by income and import/export energy	7 country reports (Argentina, Brazil, Senegal, India, Kenya, South Africa, and Thailand)	21 countries	7 countries (Brazil, Cuba, Lithuania, Mexico, Russian Federation, Slovakia and Thailand)	Only for Thailand in present study (this list of indicators could be applied for other countries)
4	Level of analysis	National level	National level	National level	National level and Household level	National level	National level	National level
5	Time frame used	10 years average (1970s, 1980s, 1990s, and 2000s)	2006	1999–2006. AI for 2006	2002–2006	2004 and 2030	1981–2000 (Thailand)	1986–2030
6	Scenarios analysis	–	–	–	Done for few indicators	–	–	Three scenarios
	Major output	Energy security of selected countries	Energy sustainability country index	Assessment index (AI)	Energy security assessment of selected countries	Energy security assessment	Energy indicators for sustainable development (EISDs)	Energy Security Assessment

5.2.2. Energy resource diversification (SWI)

Shannon–Wiener index (SWI) is used to assess the supply side of energy security [27]. High value of SWI represents a more diversified energy resource mix and the maximum SWI means there is equal share of all type of fuels (i.e., for six energy resources, the maximum SWI is 1.79). Fig. 7 shows the trend of SWI during 1986–2010. LCS scenario presents an improvement of the energy resource diversification (SWI) in Thailand (the maximum in 2030 is 1.6), while CP scenario provides a steady SWI at around 1.4 during 2010–2030. HEG&LC scenario presents an improvement of SWI during 2010–2020, but then it would decrease to 1.4 in 2030.

5.3. Environmental dimension

Two indicators are used to represent the environmental parameters.

5.3.1. Non carbon intensive fuel portfolio (NCFP)

A high non-carbon incentive fuel portfolio (NCFP) reflects a greater potential of environmental improvement [8]. As shown in Fig. 8, the highest share of non-carbon fuel was 35% in 1986, and it declined to 17% in 1995, due the high consumption of coal, oil and natural gas. NCFP increased in 2000 and varied between 20% and 22% until 2009. In the LCS scenario, NCFP would increase significantly to 33% in 2030, while in the CP scenario, the NCFP would be constant at around 20% during 2010–2030. In the HEG&LC scenario, NCFP would be 26% in 2015, and thereafter, it would decrease to 17% in 2030.

5.3.2. CO_2 emission

Fig. 9 illustrates that the CO_2 emission continuously increased during the last 23 years, and Thailand emitted more than 200 $MtCO_2$ in 2009. In future, the CO_2 emission would reach 1000 $MtCO_2$ in the HEG&LC scenario (world CO_2 of current policy scenario would be 40,009 $MtCO_2$ [6]). In this scenario, CO_2 emission per capita and CO_2 emission per GDP would increase to 14 tCO_2 per capita and 80 $kgCO_2$ per 1000 Baht, respectively. On the other hand, the LCS and CP scenarios show better control of CO_2 emission at around 400 $MtCO_2$ in 2030. They also show the improvement of CO_2 per capita and CO_2 per GDP. In the LCS scenario, CO_2 per capita and CO_2 per GDP would be 5 tCO_2 per capita and 24 $kgCO_2$ per 1000 Baht, while it would be 6 tCO_2 per capita and 53 $kgCO_2$ per 1000 Baht in the CP scenario.

5.4. Energy market

5.4.1. Net energy import dependency (NEID) and energy import

Net energy import dependency (NEID) is a commonly used indicator for assessing energy security [22] and a high NEID implies low energy security. The NEID of Thailand has been fairly constant since 1986, and it has only slightly improved from 27% to 25% in 2009. It is mainly because of increased domestic production of coal and natural gas. However, the actual energy

Table 7
Thailand Energy Security Indicators in 2009 and 2030 for the three scenarios.

Energy security indicator	Scenario	2009	2030	% Change*
	Current policy	25	20	−20%
Energy intensity	High economic growth & least cost	25	29	16%
kgoe per 1000 Baht	Low carbon society	25	10	−60%
	Current policy	8	7	−13%
Oil intensity	High economic growth & least cost	8	7	−13%
kgoe per 1000 Baht	Low carbon society	8	4	−50%
	Current policy	1540	2,500	62%
Energy per capita	High economic growth & least cost	1,540	4,642	201%
kgoe per capita	Low carbon society	1,540	2,270	47%
	Current policy	479	900	88%
Oil per capita	High economic growth & least cost	479	1,100	130%
kgoe per capita	Low carbon society	479	700	46%
	Current policy	30%	29%	−1%
Transportation sector	High economic growth & least cost	30%	31%	1%
% share of TPES	Low carbon society	30%	29%	−1%
Oil use in Transportation % share of total Oil consumption	Current policy	69%	45%	−24%
	High economic growth & least cost	69%	77%	8%
	Low carbon society	69%	61%	−8%
	Current policy			
	Crude oil	3	–	−100%
	Condensate	8	N/A	N/A
	Natural gas	10	–	−100%
	Lignite	67	36	−46%
Resources and reserves	High economic growth and least cost			
RPR (years)	Crude oil	3	20	567%
	Condensate	8	N/A	N/A
	Natural gas	10	26	160%
	Lignite	67	23	−66%
	Low carbon society			
	Crude oil	3	–	−100%
	Condensate	8	N/A	N/A
	Natural gas	10	–	−100%
	Lignite	67	36	−46%
	Current policy	1.4	1.4	0%
SWI	High economic growth and least cost	1.4	1.5	7%
	Low carbon society	1.4	1.6	14%
	Current policy	22%	20%	−2%
NCFP	High economic growth and least cost	22%	17%	−5%
% of TPES	Low carbon society	22%	33%	11%
	Current policy	200	468	134%
CO_2 emission	High economic growth and least cost	200	1000	400%
$MtCO_2$	Low carbon society	200	345	73%
	Current policy	4	7	75%
CO_2 per capita	High economic growth and least cost	4	15	275%
tCO_2 per capita	Low carbon society	4	5	25%
	Current policy	58	52	−10%
CO_2 per GDP	High economic growth and least cost	58	86	48%
tCO_2 per 1000Baht	Low carbon society	58	24	−59%
	Current policy	25%	26%	1%
NEID	High economic growth and least cost	25%	24%	−1%
%	Low carbon society	25%	21%	−4%
	Current policy	46	134	191%
Energy import	High economic growth and least cost	46	248	439%
Mtoe	Low carbon society	46	103	124%

Note * % change between 2009 and 2030.

import increased significantly because of higher energy consumption, from 9 Mtoe in 1996 to 49 Mtoe in 2005, and then reduced to 46 Mtoe in 2009 as shown in Fig. 10.

LCS scenario shows a positive trend of NEID as it would reduce to 20% in 2030, while the CP scenario shows constant NEID at 25% during 2010–2030. HEG&LC scenario shows an improvement in short term 2010–2020, but NEID would increase during 2021–2030 to reach 24%. As a result, LCS scenario provides a positive improvement of NEID and reduces energy imports as compared to other scenarios.

5.4.2. Geopolitical market concentration risk (GMC)

Geopolitical market concentration risk (GMC) indicator is used to assess the political factors associated with the (energy resource) exporting countries [11]. High value of GMC attests to

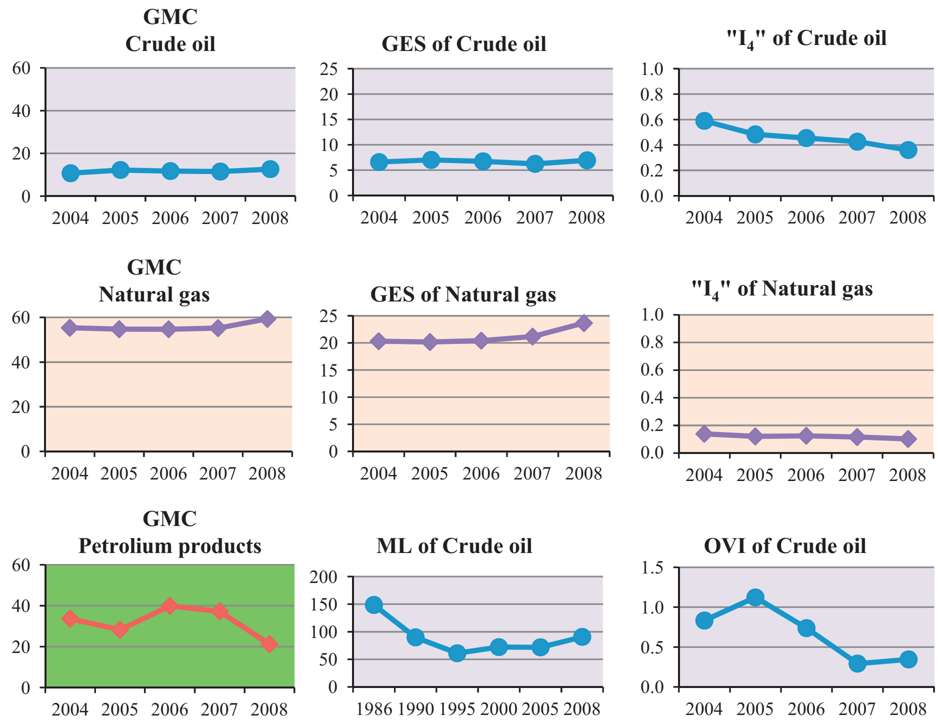

Fig. 11. Energy market indicators 2004–2008.

low political risk (the highest value of GMC is 100) [73]. During 2004–2008, there was low geopolitical risk for natural gas, as GMC varied in the narrow range 55–59, compared to crude oil and petroleum products as shown in Fig. 11, as more than 70% of natural gas consumption was supplied by domestic production. GMC of petroleum products varied in a wide range (20–40) during 2004–2008, while GMC of crude oil varied in a narrow range of 9–11 representing high risk. Thailand imported petroleum products and crude oil from many sources (33 countries), but the major shares were from United Arab Emirates, Saudi Arabia and Oman.

In 2008, Thailand imported petroleum products from Malaysia, Singapore, Indonesia, and South Korea, while crude oil was imported from United Arab Emirates, Saudi Arabia, Oman, Qatar, Yemen, Russia and Malaysia [66].

5.4.3. *Geopolitical Energy Security (GES)*

GES is obtained by considering the supply availability and the share of each fuel type in the total energy consumption to GMC index [11]. High value of GES attests high energy security.

As shown in Fig. 11, the GMC of natural gas shifted from high security level to GES lower than 25, and this represents insecurity of natural gas supply due to the limitation of reserves in the market. In contrast, there was small change of GMC and GES of crude oil, as crude oil was more easily available in the world market. Thailand imported crude oil from more than 30 countries compared to only one country for natural gas (Myanmar). The overall assessment of GES of natural gas and crude oil were low and this presents a high energy insecurity of supply.

5.4.4. *Energy security indicator (I_4)*

Jansen et al. [26] developed "I_4" for energy security assessment of European countries by aggregating energy imports, political stability in the producing regions and for the proven regional reserves with respect to the annual production in the home region. A low value of "I_4" represents a worse energy supply situation.

As shown in Fig. 11, this indicator for Thailand shows that crude oil supply situation significantly declined from 0.589 in 2004 to 0.360 in 2008, while natural gas supply declined from 0.139 to 0.102 during 2004–2008. This was mainly because of high energy consumption which increased the depletion rate of proven reserves of oil and natural gas. Moreover, the exploration rate of new reserves of natural gas and crude oil was much lower than the growth rate of demand.

5.4.5. *Market liquidity (ML)*

Market liquidity is defined as the ratio of world oil export to the net oil import of country [24]. It presents the availability of oil in world market compared to demand of oil which cannot be supplied by domestic oil production. Therefore, high ML indicates high extra oil supply.

During 1986 to 1995, ML decreased significantly due to increased oil import. After that, ML increased corresponding to the decreasing oil import. In 2008, the oil available in the world market was 91 times of Thailand's oil import demand as shown in Fig. 11. However, this index does not take world oil reserves, growth rate of oil demand and production capacity of other countries into consideration. These could be very important factors for long term security supply when indigenous reserves get depleted.

5.4.6. *Oil vulnerability indicator (OVI)*

OVI was developed by Gupta [24] which mainly considers market risk and supply risk of oil. High value of OVI implies high oil vulnerability. The OVI for Thailand indicates an improvement of oil vulnerability index during 2004–2008 as shown in Fig. 11. OVI was 0.29 in 2007, and was lower than in 2008 (0.35). This was mainly because of higher oil price in 2008 even though there was higher oil consumption in 2007 than in 2008. Therefore, this indicator is more sensitive to oil price rather than the quantity of oil consumption.

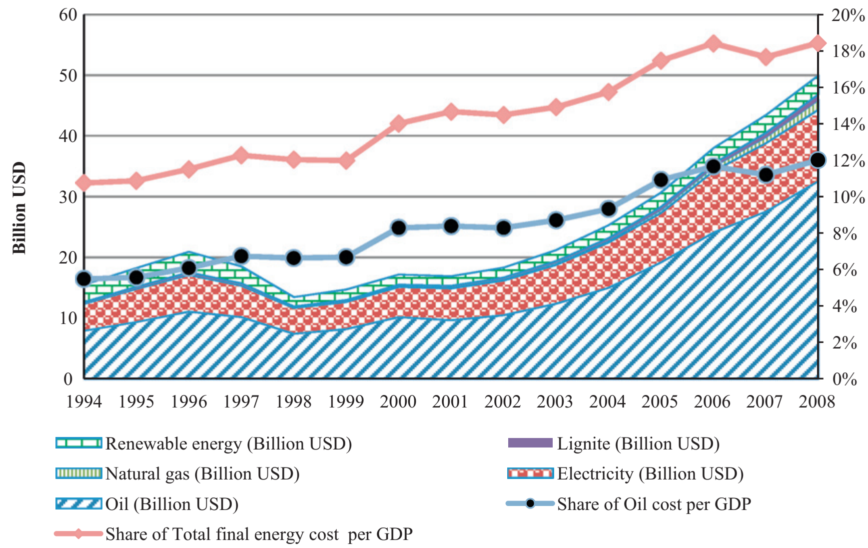

Fig. 12. Energy expenditure during 1994–2008.

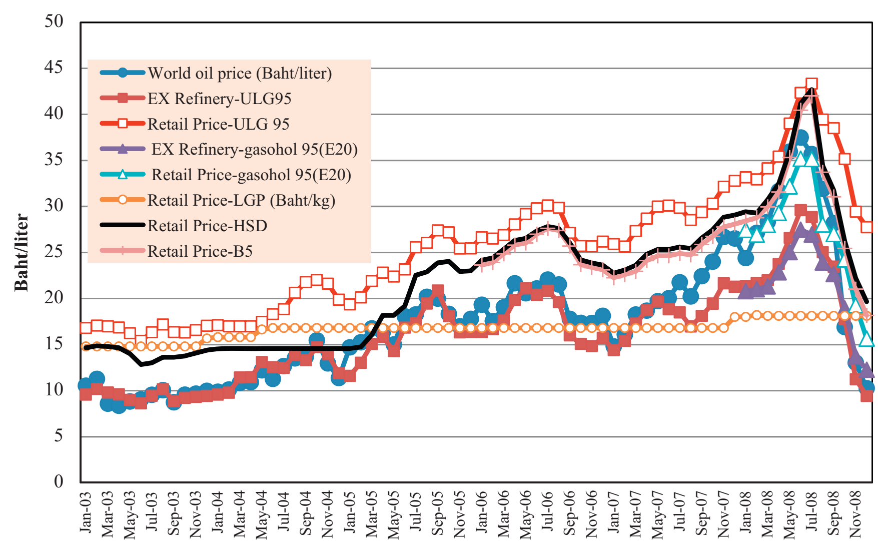

Fig. 13. Monthly petroleum products price 2003–2008.

5.5. Energy expenditure

The energy expenditure of Thailand during 1994–2008 (Fig. 12) increased significantly from 15.5 billion USD in 1994 to 50 billion USD in 2008. Energy cost as a share of GDP increased from 11% in 1994 to 18% in 2008. Of this, oil expenditure contributed about 12% followed by electricity 4%, and others 2%.

An analysis of petroleum products price in Thailand during 2003–2008 compared to world oil price shows that the retail price of petroleum products in Thailand closely followed the world oil price as shown in Fig. 13. To address and prevent a shortage of fuel due to increase in world oil price, the Thai government established the oil fund in 1977. This fund works to control the retail price of petroleum products. Government levies oil fund tax from petroleum producers and importers including their exchange rate revenue during cheap world oil price. When the world oil price increases, the government uses the oil fund to compensate the petroleum producers and importers for controlling the retail price so that it does not rapidly increase in the same manner as the world oil price increases. As a result, it helps reduce the impacts of petroleum price fluctuation on the consumers [76].

Oil fund is mainly used to subsidize the retail price of gasoline, diesel and LPG. Gasohol E10, E20 and biodiesel B5 are alternative options for fuel substitution, and were subsidized by oil fund to a lower retail price than conventional gasoline and diesel at 18%, 22.5% and 2.8%, respectively, in 2008.

The above indicators (energy expenditure and petroleum products price) show that the local energy price is sensitive to the world market.

5.6. Analysis of three scenarios

The indicators obtained based on the three (future) scenarios for 2030 are compared with those of 2009 in Table 7, and are reviewed below:

- **CP scenario**
  In this pathway, the oil use in the transportation sector shows a reduction in 2030 (it would reduce by 24% and energy

intensity will reduce by 20% compared to 2009). In addition, oil intensity and CO_2 per GDP would be reduced by 13% and by 10%, respectively. Other indicators, such as, energy per capita increases by 62%, energy import increases by 191% and CO_2 emission increases by 134% in 2030 compared to 2009, and shows a negative trend.

CP scenario shows an improvement in energy security in 2030 considering the following indicators: energy intensity, SWI, NCFP, CO_2 per GDP, and NEID indicators.

- **HEG&LC scenario**

This scenario shows improvement of domestic reserves of crude oil and natural gas due to the increase of energy import by 439% in 2030 compared to 2009. The scenario also shows improved SWI due to the increasing share of coal and reduced oil and natural gas share in the primary energy supply. But, it leads to an increase in CO_2 emissions by 400% as compared to 2009, even if Thailand installs nuclear power plants in 2030 to provide14 Mtoe. HEG&LC scenario shows that there is an increase in energy import significantly but energy diversity is also improved, and thus leads to a reduction in the net energy import dependency by 1%. In addition, this scenario provides the best reserve to production ratio of crude oil and natural gas. This provides co-benefits on long-term reserves and will reduce the influence of world's oil price fluctuation.

In the short term, HEG&LC scenario shows improvement in SWI, NCFP, and NEID, and from a longer term perspective, HEG&LC scenario shows improvement in oil intensity, and RPR of crude oil and natural gas.

- **LCS scenario**

This scenario shows improvement in many energy security indicators in 2030 compared to 2009. The energy demand of this scenario indicates that the energy intensity is reduced by 60% (reduces from 25 kgoe per 1000 Baht in 2009 to 10 kgoe per 1000 Baht in 2030). Oil intensity reduces by 50% (from 8 to 4 kgoe per 1000 Baht), and oil use in transportation sector reduces by 8% (reduce from 69% in 2009 to 61% in 2030). However, LCS scenario may not be able to reduce the energy consumption per capita, which would increase by 47% (increase from 1540 to 2270 kgoe per capita).

In the LCS scenario, the availability of energy supply resources shows an increase in SWI of 14%, but crude oil and natural gas will be depleted in 2015 and 2022, respectively.

In terms of environmental parameters, the CO_2 emission in 2030 compared to 2009 will be increased by 73% (from 200 to 345 $MtCO_2$), while there will be a reduction in CO_2 per GDP by 59% (from 58 to 24 tCO_2 per 1000 Baht), and NCFP shows an increase of 11% (or NCFP 33% of total primary energy supply in 2030).

In the energy market perspective, NEID in the LCS scenario shows a reduction by 4% (reduces from 25% in 2009 to 21% in 2030), but energy import increases by 124% (from 46 Mtoe in 2009 to 103 Mtoe in 2030).

In summary, the LCS scenario reduces the adverse impact on environment (reduction by 123 $MtCO_2$ in 2030 compared to CP scenario) and provides an improvement of energy

Table A.1
Energy security definition.

Country/ agency	Energy security definition	Source
WEC	"Energy security, defined by consuming countries as securing sufficient energy supply at affordable prices to sustain economic development, is an enduring concern for policymakers. For energy suppliers, and especially exporters, security of demand is a continuing concern, addressed in part by ensuring a broad energy demand diversity covering countries, industries and uses for energy"	WEC [13]
APERC	"The ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy. Several factors influence the 'security' of energy supply, for example: (1) the availability of energy resources/reserves (2) The ability of an economy to acquire supply to meet its projected energy demand; (3) The level of an economy's energy resource diversification and energy supplier diversification; (4) Accessibility to fuel resources, and (5) Geopolitical concerns surrounding resource acquisition"	APERC [8]
IEA	"Energy security defined as access to adequate, affordable and reliable supplies of energy have evolved over time, with changes in the global energy system, and new perceptions about the risks and potential costs of supply disruptions"	IEA [19]
Brazil	"Energy security, however, does not only mean covering the shortfall in energy requirements, but also giving access to energy to greater number of people. And that should go beyond basic means giving them enough energy that they can use for their livelihood. This is absolutely appropriate to the Brazilian household sector"	Goldenberg et al., [15]
India	"We are energy secure when we can supply lifeline energy to all our citizens irrespective of their ability to pay for it as well as meet their effective demand for safe and convenient energy to satisfy their various energy needs at competitive prices, at all times and with a prescribed confidence level considering shocks and disruptions that can be reasonably expected"	TERI[18]
Japan	"Securing the amount of energy required for people's life, economic and social activities, defense and other purposes for acceptable prices" There are 7 majors elements; (1) the primary energy self-sufficiency rate, (2) the degree of diversification of energy import source countries, (3) the degree of diversification of energy sources, (4) the degree of transportation risk management, (5) the degree of domestic risk management, (6) the degree of demand conservation and (7) the degree of supply interruption risk management	Murakami et al., [12]
Kenya	"Assuring adequate energy supply through diversification of sources and mixes in a cost effective manner"	Karekezi et al., [16]
Senegal	"To secure for all the access to energy products in sufficient quantity, of good quality and at an affordable price to meet the economic growth needs, the fight against poverty and development without harming the environment"	ENDA [17]
South Africa	"Energy security means ensuring that diverse energy resources, in sustainable quantities and at affordable prices, are available to the South African economy in support of economic growth and poverty alleviation, taking into account environment management requirements and interactions among economic sectors"	Energy Research Center [14]
Thailand	"Develop energy source in the country for greater self-reliance in order to increase energy stability and to meet sufficient demand by expediting the exploration and development of energy sources at both domestic and international levels through negotiation with neighbouring countries at the government level for joint development; develop energy mix to reduce sourcing risk, price volatility, and reduce production cost; encourage electricity production from renewable energy, particularly from small or very small scale electricity generating projects, as well as study the appropriateness of alternative energy for electricity generation"	EPPO [10]
USA	Refer to "a resilient energy system would be capable of withstanding threats through a combination of active, direct security measures – such as surveillance and guards –and passive or more indirect measures-such as redundancy, duplication of critical equipment, diversity in fuel, other sources of energy, and reliance on less vulnerable infrastructure"	Brown and Pound, [9]

security from a long term perspective. LCS and CP provide better improvement on energy intensity and lower energy import compared to HEG&LC scenario. But, the reserve to production ratio of crude oil and natural gas is poor and leads to high vulnerability of energy security in the long term. In addition, after 2015 and 2022, Thailand would depend on oil and natural gas import.

Therefore, the combination of HEG&LC as short term strategy for 2010–2015 and LCS for long term strategy for 2016–2030 would provide more flexibility in the economic transition and help improve energy security in Thailand.

6. Comparison of energy security indicators for Thailand

This section presents a comparative summary of Thailand's energy security indicators based on five earlier studies UNDESA [25], APERC [8], GNESD [31], WEC [13], and the present study. The major observations are:

- Indicators of present study, namely, energy intensity, energy per capita, RPR, GMC, GES and I_4, have their sub-indicators classified by fuel types (coal, crude oil, and natural gas). These indicators show that crude oil is the critical fuel for energy security of Thailand. This is consistent with the observations of the other studies (GNESD and APERC).
- "B5: energy security" is a sub-indicator of AI studied by WEC. It is a composite indicator from five indexes, namely, SWI, energy investment per total investment, capacity margin of electricity, stock of oil/critical fuels, and level of import per consumption. The score of B5: Energy security was 6.2 (max. score is 10) for Thailand. It showed that in 2006, the energy security of Thailand was at the same rank as Argentina, China, Iran (Islamic Rep.), Lithuania, Namibia, Poland, and Tunisia [13].
- RPR of coal, oil and natural gas studied by GNESD were calculated based on the sum of proven reserves, probable reserves and possible reserves. The result shows that in 2006, RPR of coal was 150 years, RPR of oil was 8.2 years, and RPR of natural gas was 37 years [31]. But in the present study, RPRs were calculated by considering only the proven reserves, and therefore, shows lower RPR values.
- SWI in the present study was based on six fuel types; coal, oil, natural gas, hydro, nuclear and renewable energy. GNESD classified this in terms of petroleum products, fuel wood, and agriculture residue, and so the quantitative values are different. SWI in 2002 was 1.62 and increase to 1.65 in 2006 reported by GNESD [31], while in the present study, SWI was 1.38 and 1.39, respectively. Both studies show that in 2006 energy supply had more diversity than in 2002. GNESD also used Herfindhal–Hirshman index (HHI) to measure the diversification of energy resource.
- APERC calculated NEID based on five fuel types, but the present study applied six fuel types. Therefore, the weighted source diversification effects on the value of NEID results in lower energy import dependency (in 2004 was 26%) when higher diversification of supply in present study compared to APERC result (NEID was 38% in 2004) [8]. In addition, the

Table A.2
Energy security indicators based on energy demand.

No.	Indicator	Equation	Data requirement and definition	
1	Energy and oil intensity	$OI=\frac{\text{Oil consumption}}{\text{GDP}}$, $EI=\frac{\text{TPES}}{\text{GDP}}$	EI	Energy intensity (kgoe per 1000 Baht)
			TPES	Total primary energy supply (Mtoe)
			GDP	Gross domestic production (billion Baht)
			OI	Oil intensity (kgoe per 1000 Baht)
2	Energy and oil use per capita	$\text{Oil use per capita}=\frac{OC}{pop}$, $\text{Energy use per capita}=\frac{TPES}{pop}$	TPES	Total primary energy supply (Mtoe)
			OC	Oil consumption (Mtoe)
			pop	Population (million)
3	Share of transport sector	$\text{Trans share}=\frac{\text{Energy}_{trans}}{\text{TFEC}}$	Trans share	Share of energy consumption in transportation (%)
			TFEC	Total final energy consumption (Mtoe)
			Energy trans	Energy consumption in transportation sector (Mtoe)
4	Share of oil use in transport sector per total oil use	Historical data of oil consumption, domestic oil production, and import oil	Total oil consumption in all sectors (Mtoe)	
			Domestic production (Mtoe)	
			Import oil (Mtoe)	
		$OS=\frac{\text{Oil consumption in Transportation}}{\text{Total oil consumption in all sectors}}$	OS	Share of oil in transportation sector (%)
			Oil consumption in transportation sector (Mtoe)	
			Total oil consumption in all sectors (Mtoe)	

Table A.3
Energy security indicators based on energy supply.

No.	Indicator	Equation	Data requirement and definition	
1	Resource estimate	–	Proven reserve of oil (Mtoe)	
			Proven reserve of natural gas (Mtoe)	
			Proven reserve of coal (Mtoe)	
2	Reserve to production ratio (RPR)	$RPR=\frac{\text{Proven reserve of fuel } i}{\text{Domestic production of fuel } i}$	Proven reserve of each type of fuel (Mtoe)	
			Domestic production of each type of fuel (Mtoe/year)	
3	Diversity index	$SWI=-\sum S_i \times \text{Ln}\,(S_i)$	SWI	Shannon–Wiener index
			S_i	Share of fuel i in total primary energy supply (TPES) (%)

Table A.4
Energy security indicators based on environmental parameters.

No.	Indicator	Equation	Data requirement and definition	
1	Non carbon incentive fuel portfolio (NCFP)	$\mathrm{NCFP} = \frac{((\text{Hydro PED})+(\text{Nuclear PED})+(\text{NRE PED}))}{\text{TPED}}$	NCFP	Non-carbon intensive fuel portfolio (%)
			Hydro PED	Primary energy demand of hydro power (Mtoe)
			Nuclear PED	Primary energy demand of nuclear (Mtoe)
			NREPED	Primary energy demand of new and renewable energy (Mtoe)
			TPED	Total primary energy demand (Mtoe)
2	CO_2 emission	$CO_2 = \sum_{i=1}^{n} EFCO_{2i} \times EC_i$	CO_2	Total CO_2 emission (tCO_2)
			$EFCO_{2i}$	Carbon emission factor of fossil fuel type i (tCO_2/TJ) (IPCC2006)
			EC_i	Energy consumption of fossil fuel type i (TJ)

Table A.5
Energy security indicators based on energy market.

No.	Indicator	Equation	Data requirement and definition	
1	Energy import	$\sum_{i=1}^{n} \mathrm{IM}_i/\mathrm{TPES}$	IM_i	Import of energy carrier i (Mtoe)
			TPES	Total primary energy supply (Mtoe)
2	Net energy import dependency (NEID)	$\mathrm{NEID} = \frac{\sum_i m_i p_i \ln p_i}{\sum_i p_i \ln p_i}$	NEID	Net energy import dependency (%)
			m_i	Share in net imports of energy carrier i (%)
			p_i	Share in total primary energy supply (TPES) of energy carrier i (%)
3	Geopolitical market concentration risk (GMC)	$\mathrm{GMC}_f = \sum_i r_i \times (S_{if})^2$	GMC	Geopolitical market concentration risk
			r_i	Political risk rating of country i
			S_{if}	Share of each supplier i of fuel f
4	Geopolitical Energy Security (GES)	$\mathrm{GES} = \sum_f \left[\left(\sum_i r_i \times (S_{if})^2 \right) \times e^{(1/P_f)} \right] \times \frac{C_f}{\mathrm{TPES}}$	GES	Geopolitical energy security
			r_i	Political risk rating of country i
			S_{if}	Share of each supplier i of fuel f
			P_f	Total supply availability in the accessible market of fuel type f (Mtoe)
			C_f	Total consumption of fuel type f (Mtoe)
			TPES	Total primary energy supply (of all fuels) (Mtoe)
5	Market liquidity (ML)	$\mathrm{ML} = \frac{\text{World oil export}}{\text{Thailand oil consumption}}$	ML	Market liquidity
			World oil export (Mtoe)	
			Thailand oil consumption (Mtoe)	
6	Energy security indicator	$I_4 = -\sum_i (C_i^4 P_i \ln P_i)$	I_4	Indicator 4 accounting for energy imports, political stability in producing regions and for the proven regional reserves with respect to the annual production in the region concerned
		$C_i^4 = \{1-(1-r_{ik})(1-m_i)\} \times \left\{1-m_i\left(1-\frac{S_i^{m**}}{S_i^{m**,\max}}\right)\right\}$	C_i^4	Correction factor to P_i for indicator I
		$S_i^{m**} = -\sum_j (r_{ij} h_j m_{ij} \ln m_{ij})$	P_i	Share of primary energy source i in total primary energy supply
		$r_{ij} = \mathrm{Min}\left\{ \left[\frac{(R/P)_{ij}}{30}\right]^a ; 1 \right\} \ (a \geq 1)$	I	1,...,M: primary energy source index (M sources are distinguished)
			m_i	Share of net import in primary energy supply of source i
			h_j	Extent of political stability in region j, ranging from 0 (extremely unstable) to 1 (extremely stable)
			S_i^{m*}	Shannon index of import flows of resource i, adjusted for political stability in the regions of origin
			$S_i^{m*,\max}$	Maximum value of aforementioned Shannon index (equal to value 2.77 for 16 foreign regions of origin) For natural gas=0.69 for 2 origin sources, and crude oil=3.50 for 33 origin sources
			r_{ij}	Depletion index for resource i in import region j
			r_{ik}	Depletion index for resource i in home region k, for which the indicators are determined
			a	Depletion index value
			$(R/P)_{ij}$	Proven reserve-production ratio for resource i in region of origin j at reference 30 years
7	Oil vulnerability indicator (OVI)	$\mathrm{OVI}_k = \text{Market risk}_k + \text{Supply risk}_k$	OVI_k	OVI of country k
		$\text{Market risk}_k = 0.26\mathrm{OI}_k + 0.297\ \frac{\mathrm{VOM}}{\mathrm{GDP}} k + 0.216\ \text{GDP per capita}_k + 0.08\ \mathrm{OS}_k$	OI	Oil intensity at market exchange rate (toe/GDP)
			VOM/GDP	Cost of oil import in national income (%)
			GDP per capita	GDP per capita at market exchange rate
			OS	Oil share in TPES (%)
			DR/DC	Domestic oil reserves relative to total oil consumption
		$\text{Supply risk}_k = 0.07\ \frac{\mathrm{DR}}{\mathrm{DC}} k + 0.22\ \mathrm{GOMCR}_k + 0.11\ \mathrm{ML}$	GOMCR	Geopolitical oil market concentration risk
			ML	Market liquidity

Table A.6
Energy security indicators based on energy expenditure.

No.	Indicator	Description	Data requirement and definition
1	Oil or energy expenditures	The annual energy or oil expenditure per GDP	Oil (billion Baht) Electricity (billion Baht) Natural gas (billion Baht) Lignite (billion Baht) Renewable energy (billion Baht) TFC (billion Baht) GDP at current price (billion Baht) Share of oil cost per GDP (%) Share of total final energy cost per GDP (%)
2	Retail petroleum products price	The retail petroleum products' price	Average gasoline 95 retail price (Baht/l) Average gasohol 95 (E10) retail price (Baht/l) Average gasohol 95 (E20) retail price (Baht/l) Average LPG retail price (Baht/l) Average HSD retail price (Baht/l) Average HSD B5 retail price (Baht/l)
3	World oil price	The average world crude oil price	Average world oil price (daily, monthly, yearly)

higher value of NEID (50% in 2000) calculated by UNDESA [29] compared to present study (25.98% in same year) because UNDESA considered NEID as the ratio of total energy imports to total primary energy supply.

7. Conclusion

Nineteen quantitative energy security indicators were developed and used to present the past energy security trend of Thailand during 1986–2009, and also the future energy security of Thailand by considering three energy scenarios until 2030—high economic growth and least cost option (HEG&LC), low carbon society (LCS) and current policy (CP). The set of indicators used in this study covers seven basic criterions of energy security definition. Further studies to develop an aggregated/composite index from the set of indicators would help to present the overall energy security trend. This could be studied for each future energy scenario.

The energy insecurity of Thailand is mainly because of rising energy demand, limited (fossil) energy reserves, political market risk of energy imports and the energy price in the world market. Transportation sector is the most vulnerable because of significant increasing demand of petroleum products. This would also contribute to the high production cost of other industries.

Thailand adopted energy policies coupled with many energy conservation measures to reduce energy demand and plans to increase indigenous energy supply from cleaner energy sources during 1995–2030. In 2010, renewable energy consumption reported by DEDE accounts for 19.1% of the total primary energy supply [77]. The solid biomass consumption was 13.8 Mtoe, followed by liquid biofuel 0.82 Mtoe and biogas 0.39 Mtoe. Others contribution are as follows: hydro 20.02 ktoe, solar 5.62 ktoe, garbage 1.63 ktoe, geothermal 1.6 ktoe, and wind 0.04 ktoe [78].

The results of the trend of indicators considering three energy scenarios of Thailand indicate that the current policy shows slight improvement in energy security, while high economic growth with least cost option of energy supply system will provide an improvement of domestic energy reserves. The low carbon society scenario shows improved energy security in the long term. The energy security indicators help to provide a better understanding of Thailand energy scenario for further analysis and improvement.

Appendix

See Appendix Tables A.1–A.6.

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